Knight: Chapter 17

Work, Heat, & the 1st Law of Thermodynamics

(*Heat, The 1st Law of Thermodynamics, & Thermal Properties of Matter*)

i.e. 17.2: The Work of an Isothermal Compression

A cylinder contains 7.0 g of nitrogen gas.
How much work must be done to compress the gas at a constant temperature of 80° C until the volume is halved?

$$W = -nRT\ln\left(\frac{V_1}{V_0}\right)$$

$M = 7.0\times10^{-3}$ Kg $\quad M_{mol} = 0.028$ Kg/mol $\qquad n = \frac{M}{M_{mol}} = 0.25$ mol

$T = 353$ K

$V_1 = \frac{1}{2}V_0 \qquad W = -0.25\text{ mol}(8.31\text{ J/mol K})(353)\ln\left(\frac{1}{2}\right) = 510\text{ J}$

$W = 510$ J

Work in Ideal-Gas Processes…

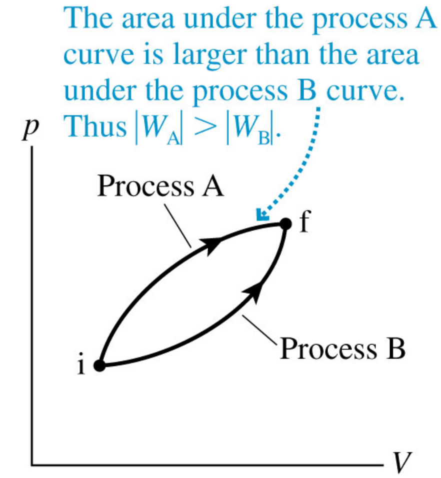
Figure (a) shows 2 different processes that take a gas from an initial state i to a final state f.

Notice:

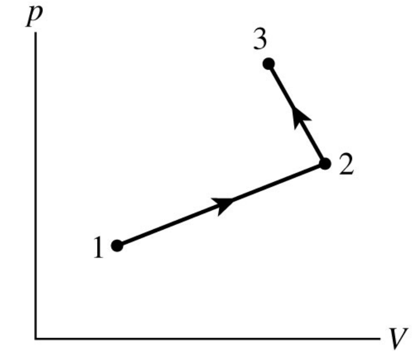
- The work done during an ideal-gas process *depends on the path followed through the pV diagram*.

- During the multistep process of figure (b), the work done is *NOT* the same as a process that goes directly from 1 to 3.

(a)



(b)



Heat, Temperature, and Thermal Energy

Thermal energy, E_{th}… (thermal energy in system)

- is *energy of the system* due to the motion of its atoms and molecules.
- is a state variable.

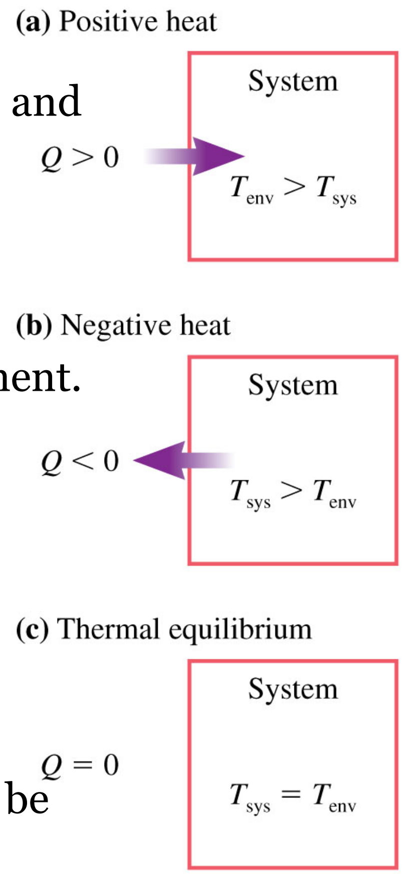
Heat, Q… (energy transfer)

- is *energy transferred* between the system & environment.
- NOT a form of energy nor a state variable.

Temperature, T… (energy per molecule)

- is a state variable that quantifies *hotness* or *coldness*.
- related to *thermal energy per molecule*.

A *temperature difference* is required in order for heat to be transferred between the system and the environment.



Units of Heat

Calorie:

The quantity of heat necessary to raise the temperature of 1 *g* of H_2O by 1°C.

$$1 \text{ cal} = 4.186 \text{ J}$$

Food Calorie:

$$1 \text{ Cal} = 1 \text{ kcal} = 4186 \text{ J}$$

The 1st Law of Thermodynamics

The *complete* energy equation is…

$$\Delta E_{sys} = \Delta E_{mech} + \Delta E_{th} = W + Q$$

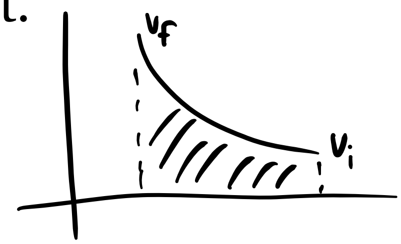
For a system *at rest*, the 1st Law of Thermodynamics is…

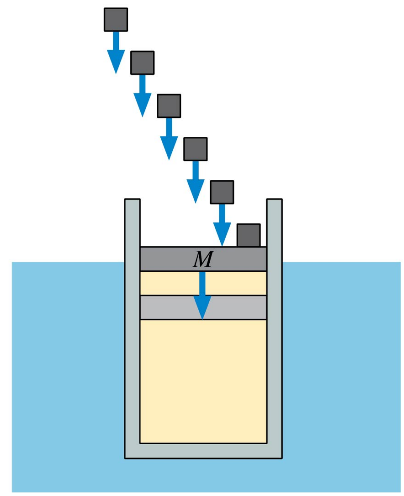
$$\boxed{\Delta E_{th} = W + Q}$$

Quiz Question 1

A cylinder of gas has a frictionless but tightly sealed piston of mass M. Small masses are placed onto the top of the piston, causing it to slowly move downward. A water bath keeps the temperature constant.

In this process:





$+W$

$\Delta E_{th} = 0$

$\Delta E_{th} = Q + W$

$Q = -W$

$W = -Q$

1. $Q > 0$.
2. $Q = 0$.
3. $Q < 0$.
4. There's not enough info to say anything about the heat.

3 Special Ideal-Gas Processes..

For an **isochoric process**..

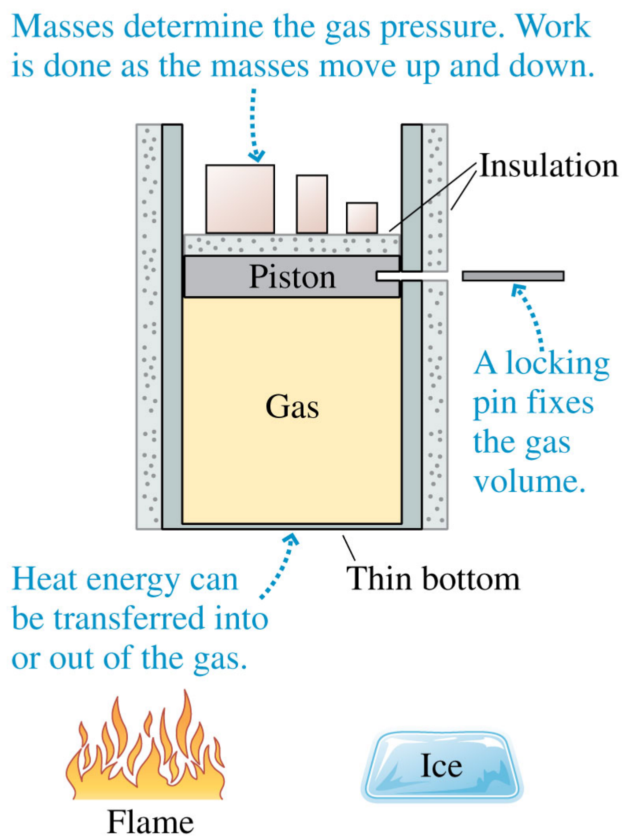
- insert the locking pin so the volume cannot change.

For an **isothermal process**…

- keep the thin bottom in thermal contact with the flame or the ice to maintain *constant* T.

For an **adiabatic process**…

- add insulation beneath the cylinder, so NO heat is transferred in or out.



3 Special Ideal-Gas Processes..

Consider an ***isochoric cooling*** process…

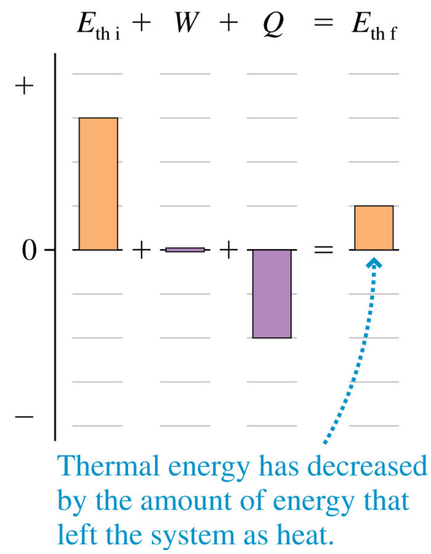
- As $W = 0$, the 1st law becomes:

$$\boxed{\Delta E_{th} = Q}$$

- H*eat* was transferred *out* of the system and the *thermal energy decreased.*

$$Q < 0 \quad \text{and} \quad \Delta E_{th} < 0$$

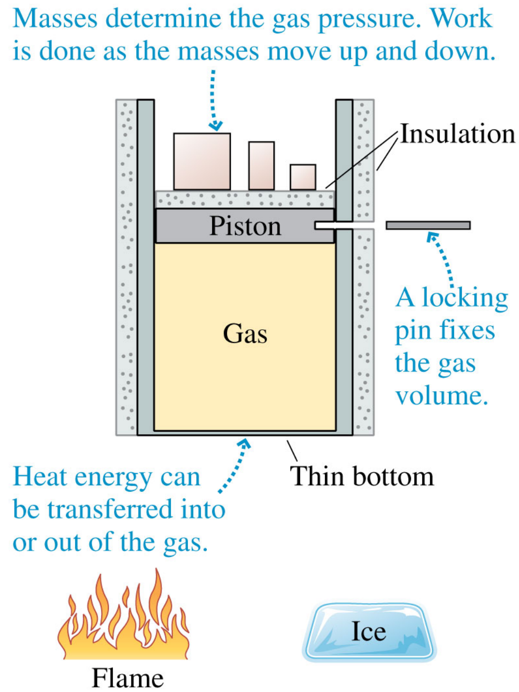
- *1st law bar chart* for a process that does NO work.



-Heat = heat leaving system

3 Special Ideal-Gas Processes..

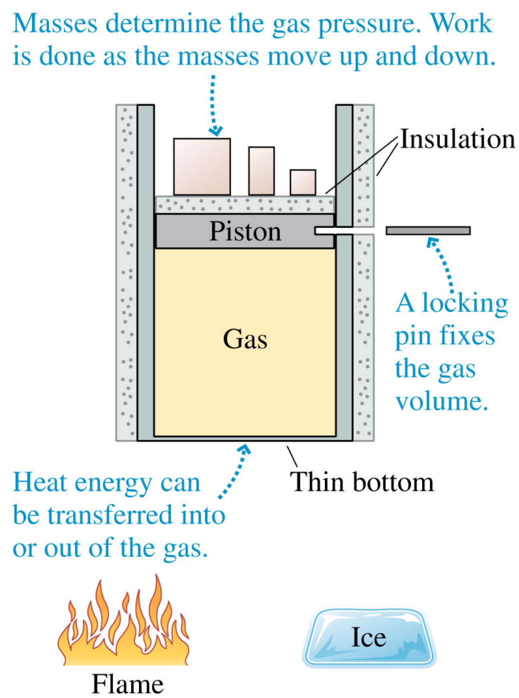
How does one *cool* the gas without doing work?



3 Special Ideal-Gas Processes..

How does one *cool* the gas without doing work?

1. Insert pin.
2. Place cylinder on ice, remove from ice when desired pressure is reached.
3. Remove masses until $p_{\text{app}} = p_{\text{gas}}$.
4. Remove locking pin.



3 Special Ideal-Gas Processes..

Consider an ***isothermal expansion***…

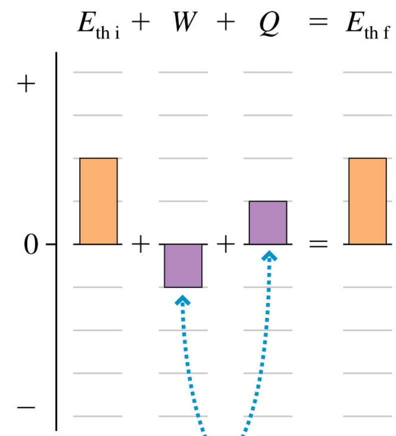
- As *temperature* doesn't change, the *thermal energy* doesn't change.

$$\Delta T = 0 \text{ and } \Delta E_{th} = 0$$

- As $\Delta E_{th} = 0$, the 1st law becomes:

$$\boxed{W = -Q}$$

- *1st law bar chart* for a process that *doesn't change the thermal energy*.



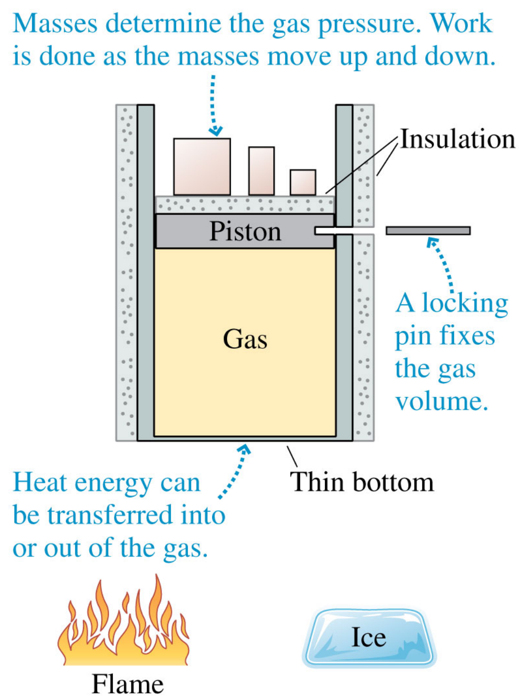
The energy that enters the system as heat leaves as work. The thermal energy is unchanged.

Notice:

$$\Delta T = 0 \text{ does NOT mean } Q = 0\,!$$

3 Special Ideal-Gas Processes..

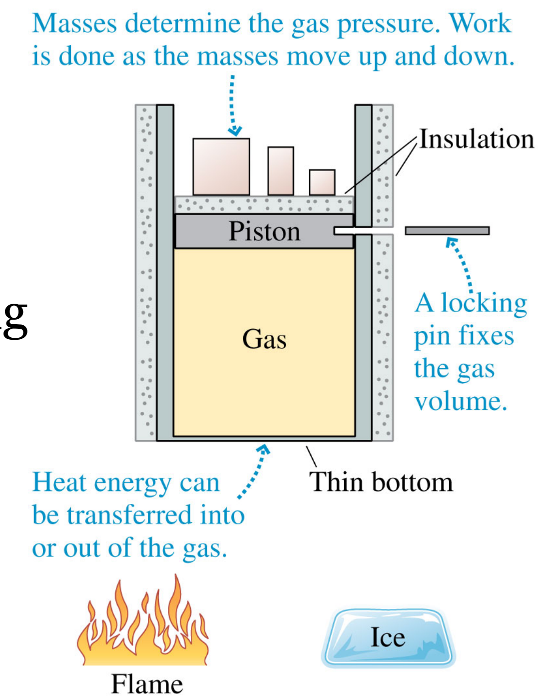
How does one *expand* the gas w/out changing it's *thermal energy*?



3 Special Ideal-Gas Processes..

How does one *expand* the gas w/out changing it's *thermal energy*?

1. Place gas on flame, gas expands.
2. Slowly remove masses to *reduce* pressure as volume *expands* (keeping *pV constant*).
3. Remove cylinder from flame when gas reaches desired volume.



3 Special Ideal-Gas Processes..

Consider an ***adiabatic compression***...

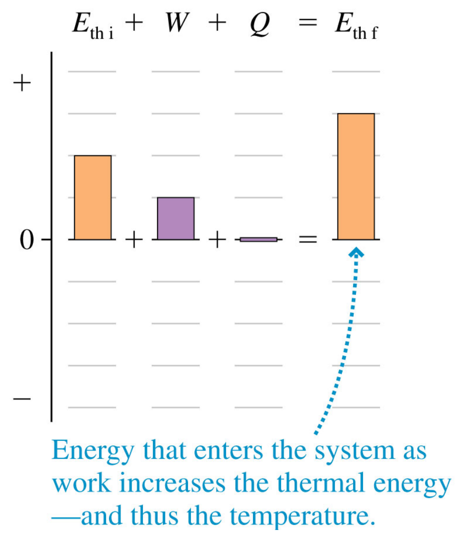
- process in which NO heat is transferred between the system & environment.

$$Q = 0$$

- As $Q = 0$, the 1st law becomes:

$$\boxed{\Delta E_{th} = W}$$

- *1st law bar chart* for a process that *transfers no heat energy*.

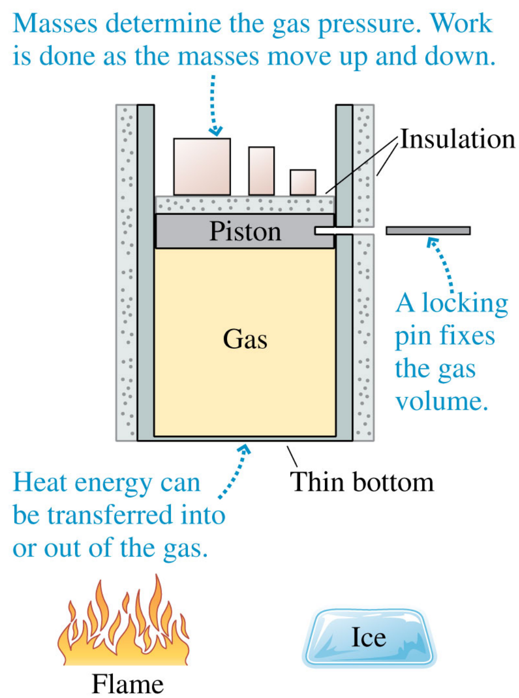


Notice:

$Q = 0$ does NOT mean $\Delta T = 0$!

3 Special Ideal-Gas Processes..

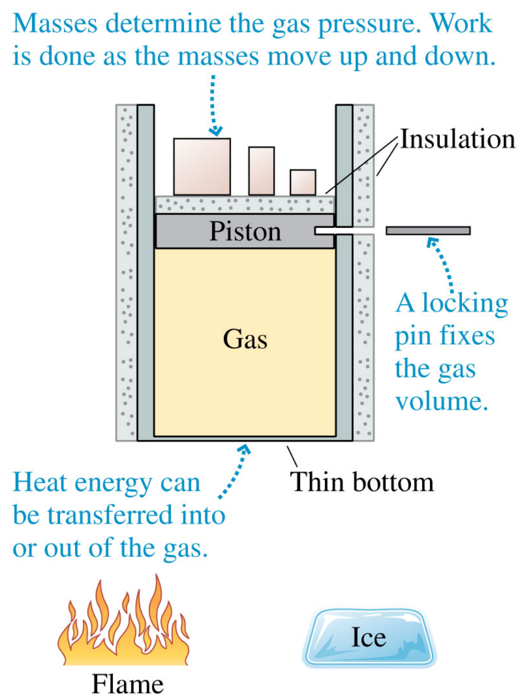
How does one *compress* the gas w/out transferring heat energy?



3 Special Ideal-Gas Processes..

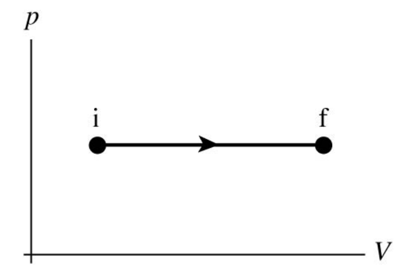
How does one *compress* the gas w/out transferring heat energy?

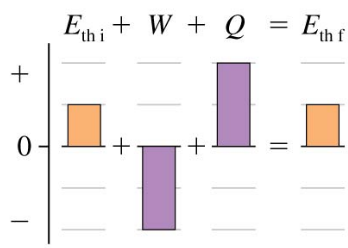
1. Insulate bottom of cylinder.
2. Add masses to increase pressure and decrease volume.
3. Stop adding masses when the gas reaches desired volume.



Quiz Question 2

Which 1st law bar chart describes the process shown in the *pV* diagram?



A.


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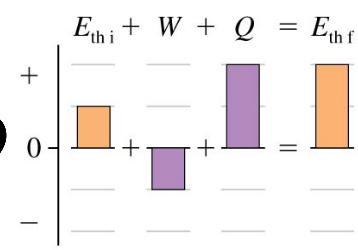

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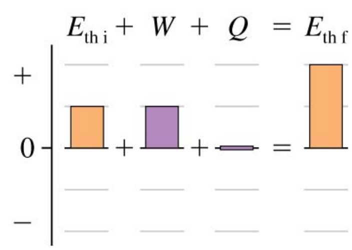

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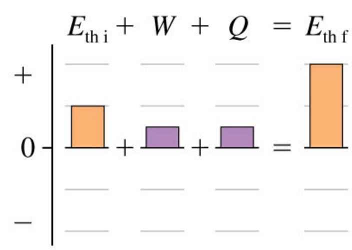

$\Delta V \uparrow$

$\Delta E_{th} \uparrow$

Thermal Properties of Matter

The ***specific heat*** is…

- the amount of energy necessary to raise the temp of 1 kg of a substance by 1 K.

$$\boxed{c \equiv \frac{\Delta E_{th}}{M\Delta T}}$$

- The thermal energy change, ΔE_{th}, needed to bring about a temp change ΔT is:

$$\boxed{\Delta E_{th} = Mc\Delta T}$$

Notice:

- If $W = 0$, then $\Delta E_{th} = Q$.
- Specific heat can be thought of as the *thermal inertia* of a substance!

Quiz Question 3

Two liquids, A and B, have equal masses and equal initial temperatures. Each is heated for the same length of time over identical burners. Afterward, liquid A is hotter than liquid B. Which has the larger specific heat?

1. Liquid A.
2. Liquid B.
3. There’s not enough information to tell.